Spacecraft Power for Cassini

Cassini's electrical power source — Radioisotope Thermoelectric Generators (RTGs) — have provided electrical power for some of the U.S. space program's greatest successes, including the Apollo lunar landings and the Viking landers that searched for life on Mars. RTGs made possible NASA's celebrated Voyager explorations of Jupiter, Saturn, Uranus and Neptune, as well as the Pioneer missions to Jupiter and Saturn. RTG power sources are enabling the Galileo mission to Jupiter and the international Ulysses mission studying the Sun's polar regions.

Extensive studies conducted by NASA's Jet Propulsion Laboratory (JPL) have shown that NASA's Cassini mission, given its science objectives, available launch systems, travel time to its destination and Saturn's extreme distance from the Sun, requires RTGs.

What Are RTGs?

RTGs are lightweight, compact spacecraft power systems that are extraordinarily reliable. RTGs are not nuclear reactors and have no moving parts. They use neither fission nor fusion processes to produce energy. Instead, they provide power through the natural radioactive decay of plutonium (mostly Pu-238, a non-weapons-grade isotope). The heat generated by this natural process is changed into electricity by solid-state thermoelectric converters.

RTGs enable spacecraft to operate at significant distances from the Sun or in other areas where solar power systems would be infeasible. They remain unmatched for power output, reliability and durability by any other power source for missions to the outer solar system.

Safety Design

The United States has an outstanding record of safety in using RTGs on 23 missions over the past three decades. While RTGs have never caused a spacecraft failure on any of these missions, they have been on-board three missions which experienced malfunctions for other reasons. In all cases, the RTGs performed as designed.

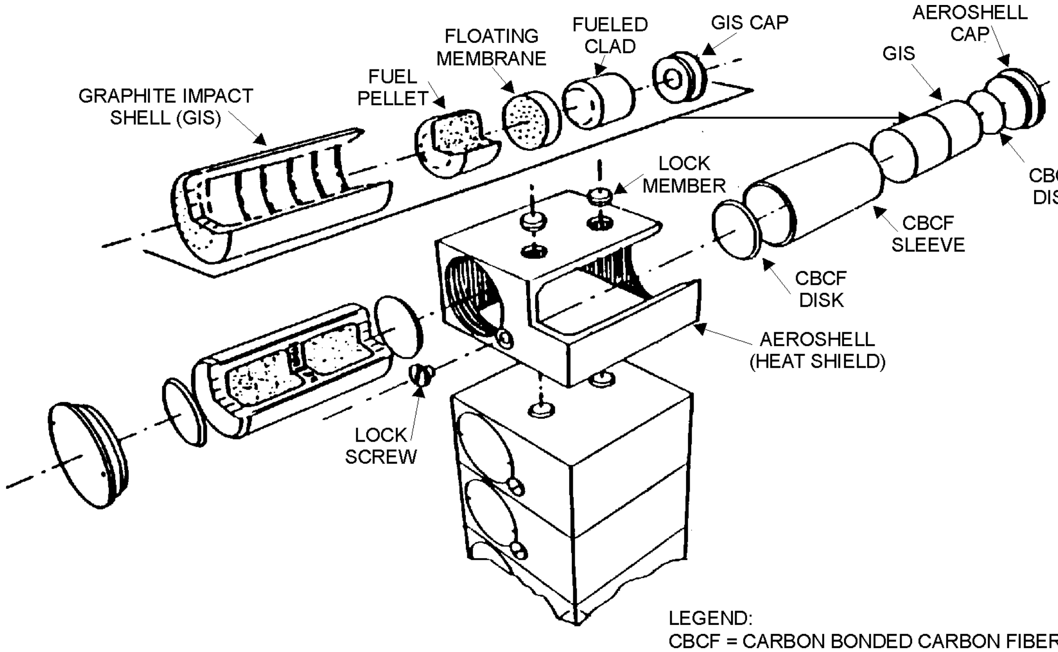
More than 30 years have been invested in the engineering, safety analysis and testing of RTGs. Safety features are incorporated into the RTGs' design, and extensive testing has demonstrated that they can withstand physical conditions more severe than those expected from most accidents.

First, the fuel is in the heat-resistant, ceramic form of plutonium dioxide, which reduces its chance of vaporizing in fire or reentry environments. This ceramic-form fuel is also highly insoluble, has a low chemical reactivity, and primarily fractures into large, non-respirable particles and chunks. These characteristics help to mitigate the potential health effects from accidents involving the release of this fuel.

Second, the fuel is divided among 18 small, independent modular units, each with its own heat shield and impact shell. This design reduces the chances of fuel release in an accident because all modules would not be equally impacted in an accident.

Third, multiple layers of protective materials, including iridium capsules and high-strength graphite blocks, are used to protect the fuel and prevent its accidental release. Iridium is a metal that has a very high melting point and is strong, corrosion-resistant and chemically

The multiple protective layers of an RTG heat source. ➤➤➤➤➤



compatible with plutonium dioxide. These characteristics make iridium useful for protecting and containing each fuel pellet. Graphite is used because it is lightweight and highly heat-resistant.

Potential RTG accidents are sometimes mistakenly equated with accidents at nuclear power plants. It is completely inaccurate to associate an RTG accident with Chernobyl or any other past radiation accident involving fission. RTGs do not use either a fusion or fission process and could never explode like a nuclear bomb under any accident scenario. Neither could an accident involving an RTG create the acute radiation sickness similar to that associated with nuclear explosions.

NASA places the highest priority on assuring the safe use of plutonium in space. Thorough and detailed safety analyses are conducted prior to launching NASA spacecraft with RTGs, and many prudent steps are taken to reduce the risks involved in NASA missions using RTGs. In addition to NASA's internal safety requirements and reviews, missions that carry nuclear material also undergo an extensive safety review involving detailed verification testing and analysis. Further, an independent safety evaluation of the Cassini mission will be performed as part of the nuclear launch safety approval process by an Interagency Nuclear Safety Review Panel (INSRP), which is supported by experts from government, industry and academia.

Non-Nuclear Alternatives to RTGs

JPL studies have concluded that neither fuel cells nor spacecraft batteries demonstrate the operational life needed for planetary missions, whose duration can exceed 10 years from launch. In addition, the large mass of batteries that would be needed to power a mission such as Cassini greatly exceeds current launch vehicle lift capabilities.

JPL's rigorous analysis has also taken into account the advances in solar power technologies that have occurred over the last decade. The conclusion reached by the researchers at JPL is that solar technology is still not capable of providing sufficient and reliable electrical power for the Cassini mission. The mass of solar arrays required would make the spacecraft too heavy for available launch vehicles. Even if a sufficiently powerful launch vehicle were available for an all-solar Cassini, other limitations exist with current and near-term solar technologies, including:

1. The behavior of solar cells at vast distances from the Sun is not well understood and would add significant risk to the success of a solar-powered mission to Saturn. Saturn is located approximately 1.42 billion kilometers (882 million miles) from the Sun, nearly twice as far from the Sun as Jupiter, the next closest planet.

2. The size of solar arrays that would be needed, about one-quarter the area of a football field, would not only be difficult to deploy reliably, but would significantly increase the orbiter's moments of inertia, making turns and other timely maneuvers extraordinarily difficult to perform. This would severely inhibit Cassini's ability to achieve its science objectives.

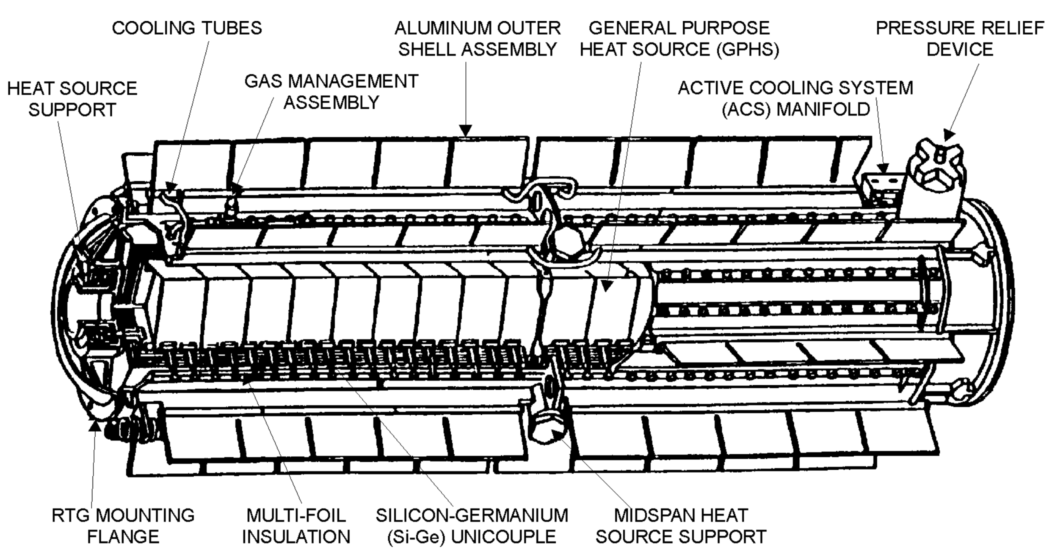
3. The large arrays would seriously interfere with the fields of view of many of the science experiments and navigation sensors, further limiting the Cassini mission's ability to achieve the science objectives.

4. Large arrays could generate serious electromagnetic and electrostatic interference, which would adversely impact the operation of the science experiments and the Cassini spacecraft's communications equipment and computers.

Cassini's Earth Swingby

By aiming a spacecraft so that it passes very close to a planet or moon, it is possible to boost the spacecraft on to still more distant destinations with greater velocity. Called the "slingshot effect" or, more properly, a gravity-assist swingby, this maneuver has become an established method of launching massive, instrument-laden spacecraft to the outer planets. Cassini plans to make use of this technique when it swings by Venus twice, then the Earth and Jupiter to reach its ultimate destination of Saturn.

The Earth swingby does not represent a substantial risk to Earth's population because the probability of a reentry during the maneuver is extremely low, less than one in one million. NASA's robotic planetary spacecraft have



RTGs have no moving parts and high reliability.

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performed numerous similar maneuvers with extraordinary precision. The redundant design of Cassini's systems and navigational capability allows control of the swingby altitude at Earth to within an accuracy of 3 to 5 kilometers (2 to 3 miles) at an altitude of not less than 500 kilometers (310 miles).

In addition, NASA has taken specific actions to design the spacecraft and mission in such a way as to ensure the probability of Earth impact is less than one in one million. For example, until 10 days before the Earth swingby, the spacecraft is on a trajectory that, without any further maneuvers, would miss the Earth by thousands of kilometers. The biased trajectory also strictly limits the possibility that random external events (such as a micrometeoroid puncture of a spacecraft propellant tank) might lead to Earth impact.

Radiation Hazards of Plutonium-238

Isotopes of plutonium such as Pu-238 characteristically give off short-range alpha particles, helium nuclei that usually travel no more than about three inches in air. While the fuel is contained within its iridium capsule, the alpha radiation does not present a hazard, and the external dose resulting from the low levels of gamma and neutron radiation associated with the plutonium dioxide RTG fuel generally would not represent a significant health hazard, either. External alpha radiation would be stopped by clothing, an outer layer of unbroken skin, or even a sheet of paper. The point at which Pu-238 can become a health hazard is when it is deposited into the body.

If an individual were to inhale plutonium dioxide particles of a sufficiently small size to be deposited and retained in proximity to living lung tissues, the alpha radiation could alter or kill nearby living cells. Over years or decades, the altered cells could become cancerous and form tumors in the lung. Additionally, some of this material could be dissolved in body fluids and transferred by the blood to be deposited in other organs, generally the liver and skeleton, with similar potential consequences. The ceramic form of plutonium used in RTGs, however, is not likely to shatter into fine particles that could be readily inhaled. Other exposure pathways, such as ingestion, contribute far less to health effects.

The ceramic form of plutonium dioxide fuel also has low solubility in water, so its migration in ground water and potential for uptake by plants is limited. The actual proportion of plutonium released from an RTG that could enter the food chain, if any, is small.

A common misconception is that a small amount of plutonium, such as one pound, if evenly distributed over the entire world, could induce lung cancer in every person on Earth. While plutonium can alter or kill living cells if deposited directly onto sensitive human tissue, the important point is that it must be in a form that enables environmental transport and intake by humans. Research has demonstrated that the mechanisms of plutonium dispersion into and transport through the environment, and hence into humans, are extremely inefficient.

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